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SOME METABOLIC ASPECTS OF EXTENDED SPACE FLIGHT

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ABSTRACT

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This paper reviews some of the anticipated metabolic consequences and physiologic effects of space flight. The factors which have been considered are as follows: (a) effect of immobilization and confinement, (b) cabin atmospheric requirements, (c) selection of an adequate diet for maintenance of fitness and for protection against radiation damage, and (d) the effect of metabolic periodicities on performance. These are discussed from the point of view of extended missions for which there will be no capability for re-supply or crew rotation. Several methods for maintaining optimal health and operational efficiency have been examined. It is concluded that a systematic program of exercise as well as the selection of special diets is required in order to avoid hazardous complications and to maintain man in a state of well-being.

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SOME METABOLIC ASPECTS OF EXTENDED SPACE FLIGHT

By Donald R. Young*

INTRODUCTION

In view of the rapid advances in space technology, we can expect that within 10 years methods for maintaining man in orbital flight for several months will have been developed. Since man himself will be the most important undetermined factor, it is necessary during early flights to obtain critical data relevant to his well-being. These data as well as those from ground-based laboratory experiments will provide information essential for planning more advanced space exploration.

Realistically, a mission-oriented program would have as one of its major goals, the exploration of Mars. Therefore it is timely to consider a number of essential physiological factors, bearing in mind the following considerations: (a) a flight lasting one year, (b) no possibility for re-supply, and (c) no possibility for crew rotation.

Confinement and Immobilization. The effect of prolonged immobility may well be the most serious problem encountered during space travel. The loss of fitness and general physical deconditioning associated with immobilization is due to the deterioration of the musculature and circulatory system. Immobilization studies of 6 to 7 weeks duration with volunteer subjects (ref. 1) show a general decrease in muscle strength with strength of the shoulder and arm muscles declining 9 percent, and strength of the extensor muscles of the lower legs declining 21 percent; girth dimensions of the extremities showed corresponding reductions. Early atrophic changes were evident within 7 days. Additional tests indicate that coordination, strength, speed, and endurance of muscular effort remain lowered for several weeks following immobilization (refs. 2 and 3).

Loss of muscle tone leads to an accumulation of blood in the lower extremities when the subject is in the erect or sitting position. This, in turn, results in a diminished return of blood to the heart, a reduced cardiac output and pulse pressure, and a tendency toward syncope and spells of dizziness (refs. 1 and 4). The prevalence of hemorrhages about the feet and ankles in tilt table (orthostatic) tests is evidence of increased capillary wall fragility or permeability. A diminution of blood volume during immobilization further serves to embarrass the cardiovascular system, available reports indicating a reduction of 180 to 1,117 ml in the circulating blood volume (refs. 4 and 5). There is also evidence of increased blood circulation time (ref. 4), which would favor the likelihood of blood clot formation in the large vessels. Increased circulation time will, in addition, diminish the blood perfusion rate in tissues and the rate of transportation of nutrients to the heart, brain, kidney, and other critical organs.

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While these changes may not appear too important in an unstressed subject, they become critical during a rapid and drastic change in the gravitational field. At 7.5 g, blood has the apparent weight of iron and therefore pooled blood would result in edema, rupture of capillaries, and possibly circulatory collapse. Clots in the circulatory system would be dislodged and cause infarcts in the pulmonary system. These sequelae to confinement would cause complete failure of pilot performance. The unfavorable stress of acceleration on circulation (refs. 6 and 7) could be the most important single factor determining the outcome of a manned mission.

Metabolism is also altered during prolonged inactivity. Studies of 3 to 7 weeks duration (refs. 1 and 2) show an average decline of 8 percent in the basal metabolic rate. Extensive studies of immobilization were undertaken by Deitrick and co-workers (ref. 1) with volunteer subjects consuming normal diets, providing 2,700 kilocalories daily. A significant increase in nitrogen excretion was observed during the first 5 to 8 days of immobilization. The average total nitrogen loss during the 7-week study was 54 gm, equivalent to 1.7 kg of muscle protoplasm. Urinary calcium increased on the second day of immobilization and climbed gradually, reaching a peak by the fifth week. The average total loss was 10.8 gm, equivalent to 2 percent of the total calcium content of the skeleton. This confirms earlier findings of mineral losses during immobilization (ref. 8). There were also losses of phosphorus, sulfur, sodium, and potassium. Although body weight changes were minimal, the authors found a slight tendency towards adiposity during the experimental period, but there were no unusual shifts in body water content.

Carbohydrate metabolism is deranged by prolonged physical inactivity. Blotner (ref. 9) studied the sugar tolerance of 70 non-diabetic patients confined to bed for periods of 4 months to 8 years. They were fed the routine hospital diet, 2,000 kilocalories daily, and yet they showed a diminished sugar tolerance as determined by the responses to the ingestion of a standard solution of dextrose. At this time, the level of blood sugar rose to abnormally high levels, the maximum being 364 mg; however, urinary excretion of sugar was variable and unremarkable. In those patients who later became physically active, the sugar tolerance returned to normal.

Some generalizations and systematizations may be made about the metabolic distortions indicated above. Losses of body nitrogen of 22 to 73 gm probably would be relatively unimportant to man's health and well-being. For example, studies by Keys and co-workers¹ have shown that cumulative nitrogen losses of 125 gm over a 3-week period do not produce clinical aberrations nor do they influence performance capabilities. However, loss of sulfur is important in that it may indicate a depletion of essential amino acids from the

¹Diet and performance capacity. Contract No. DA44-109-QM-1526, 1953-1958.

body. But these distortions can be corrected by the increase of a good quality protein in the dietary intake. Calcium loss is important because of both its immediate and persistent effects, the more acute problems being those associated with the deterioration of the skeletal system as well as those associated with the likelihood of urinary calculi formation. The persistence of high levels of calcium excretion, despite intake of calcium in therapeutic amounts, makes attempts to restore the normal body content of this mineral difficult. The studies reported above (ref. 1) have shown an additional average calcium loss of 3.3 gm during the first 3 weeks of recovery, following 7 weeks of immobilization; and other tests have shown a failure of experimentally depleted subjects to re-establish calcium balance, even after 7 weeks of therapeutic nutrition.

Since carbohydrate and calcium metabolism are under the direct control of the hormonal system, it may be important to investigate further the characteristics of endocrine functions during immobilization.

Several methods are available for maintaining general physical fitness and the integrity of body function in an encapsulated environment. Nutrition has been mentioned briefly as such a method. Much more, however, is known of the effect of physical exercise in the maintenance of muscular, circulatory, and cardio-respiratory integrity, and improvement of over-all body metabolism. The value of exercise has been studied extensively with regard to a large number of clinical disorders, and physical activity has been used as a therapeutic measure to avoid hazardous complications and as a means for hastening recovery during convalescence.

If space and weight limitations preclude on-board devices for standard forms of exercise, other types can be employed. Movement, such as is provided by an oscillating bed, is of considerable value in preventing the undesirable effects of immobilization. Previous tests of this bed during recumbency prevented the loss of circulatory control where the upright position was assumed, reduced calcium loss by approximately 50 percent, and reduced slightly the nitrogen loss (ref. 10). Dynamic tension, which entails the controlled stretching of muscle groups, would also be effective in offsetting the ill effects of confinement. Artificially induced activity through electrical stimulation of muscles has special merit, since this form of exercise elevates heart rate, blood pressure, and oxygen consumption, thus reproducing the physiologic effect of conventional physical activity, without producing fatigue in the usual sense (ref. 11).

The physiologic effects of immobilization are summarized in table I. In general, the studies reported show a direct relationship between physical activity on the one hand and circulatory efficiency, nitrogen, calcium, and carbohydrate metabolism on the

other. Significant interactions between metabolism and hormone function are suggested. Further studies of the influence of exercise on those factors would be desirable.

Few attempts have been made to evaluate systematically the effect of simulated weightlessness on the circulatory system and on metabolism. For experimental purposes water immersion, employing the Archimedes principle, is the closest approximation of the weightless state, at least with respect to the musculoskeletal system. Also, during immersion there is a marked decrease in the muscular effort required for most activities. The responses of one subject to 7 days of continuous immersion to the neck while resting on a reclining couch were studied by Graveline and co-workers (ref. 12). A liquid diet (Sustagen) was fed in amounts necessary to maintain body weight. Urinary nitrogen increased markedly during the experimental period, averaging 9.4 gm daily in contrast to control levels of 2.3 gm. Urine volume increased in direct relationship with the nitrogen excreted as did sodium, but urinary potassium and calcium were not altered systematically. Blood sugar showed a tendency to decline. Following immersion, tilt table tests showed a decrease in systolic pressure, and increase in diastolic pressure, with a resulting narrowing of the pulse pressure. Also, heart rate was increased.

Water immersion of shorter duration (18 hours) with 12 subjects does not confirm the finding of increased excretion of urine, nitrogen, and sodium (ref. 13). Immersion for 18 hours is possibly too short a period to induce measurable changes.

Briefly, if water immersion may be accepted as an uncomplicated simulation of the weightless state, it would appear that weightlessness and confinement have several points of mutual similarity. Notably, both lead to increased nitrogen excretion and a decreased ability of the circulatory system to compensate for postural changes in a gravitational field. Their respective effect on mineral metabolism is different. For example, confinement and inactivity result in a loss of tissue nitrogen and potassium, indicative of atrophic changes in muscles and substantial bone demineralization. In contrast, during water immersion mineral excretion is unchanged, and therefore no unusual effect on muscle tissue or the skeletal system is indicated. Body nitrogen lost during water immersion may be derived from tissues other than muscles.

Cabin Atmosphere. The choice of a cabin pressure will be based largely on engineering considerations. In order to reduce the structural requirements and to minimize the leak rates in the near-vacuum of outer space, it would be desirable to maintain pressure at less than 14.7 psi (atmospheric). Two possible cabin pressures, 5 psi and 7.3 psi, corresponding to 280 and 380 mm Hg, respectively, will be considered to provide basic guidelines for atmospheric requirements. Factors influencing the selection of an

adequate environment for these pressures are associated with (a) the known toxic properties of gases and (b) a reluctance to expose man for extended periods to other than a normal sea-level atmosphere.

The undesirable effect of gases is related directly to their partial pressure. With human subjects, exposure to pure oxygen (a) at 760 mm Hg for 24 hours caused substernal distress (ref. 14); (b) at 684 mm Hg for 65 hours resulted in bronchitis, fever, nausea, vomiting, and general malaise (ref. 15); and (c) at 418 mm Hg for 7 days showed evidence of some toxicity (ref. 16). Numerous other tests with experimental animals confirm the hazardous consequences of breathing oxygen at partial pressures in the range of 530 to 760 mm Hg (refs. 17 to 20). On the basis of the findings, it is recommended that oxygen tensions in excess of 425 mm Hg are potentially hazardous and therefore unsafe (ref. 21). Interference with the blood transport of carbon dioxide has been suggested as a basis for oxygen toxicity (refs. 22 to 24).

With the possible exception of a few relatively short term (5 to 17 days) human studies, which show no important effect of pure oxygen at a pressure of 180 mm Hg (refs. 25 and 26), the result of prolonged exposure to oxygen within the range of 150 to 350 mm Hg is unknown. In view of the marked species sensitivity to higher than normal tensions of oxygen, primates being less resistant than other mammalian species, tentative plans to subject man to higher than normal pressures of oxygen must be suspect and viewed with caution.

Because of the potentially detrimental effect of continuous breathing of oxygen at higher than accustomed levels, some consideration must be given to the selection of an inert gas as a diluent. Theoretically, helium, nitrogen, or argon would be the gases to choose from. Krypton and especially xenon are to be avoided because of their narcotic effect. Yet, selection from these three is not uncomplicated since it is well established that they exert a direct influence on metabolism. Their metabolic effect is particularly clear with molds (ref. 27) and other invertebrates for which growth rates are accelerated by these gases in the following ascending order: < argon < nitrogen < helium. The effect of helium at partial pressures of 228 to 600 mm Hg in increasing the metabolic rate over that observed in nitrogen is dramatic and established for mammalian species (refs. 28 to 32). For example, the effect of substituting helium for the nitrogen in the atmosphere on the metabolism of mice can be seen in table II. In general, helium accelerates metabolism by approximately 45 percent. Neither fasting, variations in the fat or carbohydrate content of the diet, nor adaptation to high or low environmental temperature alters the response to helium.

Ordinarily, most tests assessing the influence of inert gases employ a mixture containing nitrogen as the standard. Argon, krypton, and xenon, compared with nitrogen, are depressants or relatively narcotic. Helium and neon are relatively less narcotic than nitrogen, and thus are considered to be acceleratory. Evaluation of the effects of these gases must be based on the standard used. The importance of nitrogen per se in maintaining optimal body function is unknown.

In the absence of further information, a conservative view would dictate the selection of nitrogen as the most suitable diluent. Thus the probable atmospheric composition of a cabin maintained at 1/3 of an atmosphere would be as follows: oxygen, 155 mm Hg; nitrogen, 108 mm Hg; water vapor, 12 mm Hg; carbon dioxide and other gases, < 10 mm Hg. At a pressure of 1/2 an atmosphere, oxygen partial pressure would remain constant at 155 mm Hg; nitrogen pressure would be 208 mm Hg or approximately 380 mm Hg lower than that normally found in the earth's environment. A comparison of the earth's atmosphere with that of two possible cabin environments is shown in table III.

Another problem related to toxic gases, quite apart from that associated with normally occurring atmospheric constituents, is the potential hazard attending the use of organic polymers for cabin components in a closed ecological system. Even though temperatures in excess of 200° C are usually required to pyrolyze polymers, volatilization may occur at below-decomposition temperatures. Cellulose acetate, for example, loses 10 to 12 percent of weight in 3 days at 82° C. In addition there may also be a slow release of monomers, for example, formaldehyde from phenol formaldehyde. At a reduced pressure the rate of release of noxious substances may be even greater.

Effect of Diet. A good dietary practice is essential for health. The average daily food allowances have been determined by a number of cognizant agencies; these are shown in table IV. Not shown are allowances for sodium, potassium, phosphorus, magnesium, copper, iodine, fluorine, and trace elements; or pyridoxine, folacin, pantothenic acid, biotin, vitamin B₁₂, vitamin E, and vitamin K. A lack of knowledge precludes establishment of recommendations of daily allowances for these substances, but it is assumed that intake of a varied diet will provide sufficient amounts for good health. There are many unsolved problems in nutrition, the most popular of which are related to obesity, the type and quantity of dietary fat, trace mineral dietary interrelationships, the role of the lesser known vitamins, as well as the determination of adequate protein nutrition in health and disease.

But for the present let us consider only the effect of relatively simple dietary manipulations on the physiologic state of the organism. In the first place, studies have shown that maintenance

of body weight is a function of the frequency of meals eaten during the day and not necessarily the total food consumed. Originally, it was observed that animals fed twice daily contained almost double the body fat as did animals eating the same diet ad libitum (ref. 33). As body fat increased in the meal-eating rats, protein and water content decreased (refs. 34 and 35). Cohn (ref. 36) has compared nibbling with meal-eating, and concluded that meal-eating is associated with the following: (a) obesity; (b) the development of diabetes in partially depancreatized rats; (c) a greater elevation of serum cholesterol level with diets containing modest amounts of cholesterol, and an enhancement of the production of atherosclerosis; and (d) the development of liver disease with a high fat diet.

There are several explanations of the effect of spaced, full meals: reduction of protein synthesis, increased metabolism over alternate enzymatic pathways that lead to conservation of energy and enhanced fat production, and a reduction of thyroid activity (refs. 37 to 39). Although flooding the organism with calories through spaced full meals leads to a more economical use of food energy, apparently a number of undesirable effects occur.

Certain other considerations favor nibbling, particularly as a method of optimizing work performance through maintenance of higher levels of blood sugar. This is certainly suggested by the studies of Haggard and Greenberg (refs. 40 and 41). But further research is required to establish conclusively the best feeding schedule which satisfies all requirements of space travel.

Secondly, intestinal gas production is considered briefly because it is a source of discomfort for personnel performing vital functions in confined areas, and also because it can provide guiding information for the establishment of adequate atmospheric control systems.

Diet is an important source of gas production. Ruge (ref. 42) correlated intestinal oxygen and carbon dioxide content with the presence of food in the gastrointestinal tract, and Blair and co-workers (ref. 43) showed that maximally, 10 liters per day of gas could be produced. Vegetable diets and foods high in crude fiber increase gas production (refs. 44 to 48).

In addition, studies undertaken by the Quartermaster Food and Container Institute for The Armed Forces have shown clearly the influence of dietary protein and carbohydrate on intestinal gas formation. The effect of diet on the volume and major molecular composition of intestinal gas produced in rats was studied (ref. 49); casein, dried skim milk, and wheat protein were relatively high gas producers. The increased gas volume was related to the intestinal content of hydrogen and carbon dioxide; oxygen or methane were not affected systematically. Similar diets containing antibiotics

reduced gas volumes and amounts of carbon dioxide and hydrogen. Since purified amino acid diets, similar in composition to the above-mentioned protein diets, did not change gas production, it would appear that protein composition in itself is irrelevant. The type of carbohydrate eaten was also an important factor. Thus, corn dextrin and galactose caused higher intestinal gas volumes, with higher concentrations of hydrogen and carbon dioxide, than did dextrose or sucrose. The volume and composition of intestinal gases from rats fed diets varying in protein and carbohydrate source are shown in table V.

Thirdly, diet can play an important role in protecting against damage from radiation. Already some success has been achieved by protecting the gastrointestinal tract. Friedman and co-workers at Jefferson Medical College, Philadelphia, undertook an investigation of the effect of feeding nutritionally inert substances on injury resulting from X-irradiation. Since the breakdown of intestinal epithelium, anorexia, diarrhea, and massive hemorrhaging in the intestinal tract were symptoms associated with early deaths in irradiated animals, they reasoned that a degree of protection might be conferred by administering heavy metals (a) which were opaque to X-rays and (b) which caused a thickening of the intestinal epithelium. Experimental mice were fed diets containing up to 50-percent talcum (magnesium silicate), and as a result the mean lethal radiation dose was increased 15 percent, and the incidence of "intestinal deaths" was lowered markedly. The deleterious structural and functional changes in the intestine have been summarized (ref. 50). Internal shielding by administration of barium sulfate has also been reported to be effective; feeding of barium meals to rats prior to irradiation led to a reduction of mortality, a lower incidence of and less severe diarrhea, and a tendency for less body weight loss (ref. 51).

Also, protection of the central nervous system has been investigated. Timiras,² at the University of California, studied electroshock seizure thresholds and brain electrical rhythms in rats exposed to sublethal doses (500 r and 250 r) of whole body X-irradiation. These exposures resulted in a 15-percent decrease in the threshold for induced seizures, and alterations in electrical activity recorded from electrodes implanted in the hippocampus, reticular formation, and prepyriform cortex. Some of these changes persisted for 6 months after exposure. Hyperexcitability was associated with increased concentrations of sodium and chloride and a decreased potassium concentration in the cerebral cortex and cerebellum. A diet high in protein fed before and after irradiation protected against changes in electroshock seizure patterns. There were also indications that diets low in sodium protected against

²Relationship of dietary balance of macronutrients to resistance to low doses of whole-body radiation as measured by changes in brain function. Contract No. DA19-129-QM-1589, 1960-1962.

the undesirable effects of irradiation. On the other hand, diets high in potassium enhanced the effect of radiation.

Improvement of general body nutriture through the feeding of certain brassicaceous plants also reduces radiosensitivity. For example, several studies agree in demonstrating in cabbage (refs. 52 and 53) and broccoli (ref. 54) the presence of unknown substances which decrease mortality of X-irradiated guinea pigs by 20 to 50 percent. Also, another succulent plant, alfalfa, has been shown to be an even more effective supplement. Protection was evident by the increased body weight gains and improvement of the general health of the animal. Apparently, protection is unrelated to the vitamin, mineral, or protein content of the supplement; attempts at chemical fractionation of alfalfa in order to isolate the active factors have yielded so far inconclusive results.

In general, the magnitude of protection indicated by the above-mentioned dietary effects would warrant serious consideration, particularly when evaluated against the anticipated weight of physical shielding required in a spacecraft to achieve the same result.

Fourthly, there is an increasing body of evidence suggesting the need for formulating diets to meet individual needs. For example, there are subtle differences in the dietary protein requirements of individuals which may be determined from the fasting blood levels of essential amino acids. Dr. Winitz and co-workers at the City of Hope Medical Center are pursuing this approach in developing synthetic liquid diets for individual human feeding. In another field, Soviet investigators have explored the problem of individual responses to protein levels or the differences in fat/carbohydrate ratio of the diet on the excitability of the brain cortex. In a recent review of the Soviet literature on nutrition and higher nervous activity, Brozek (ref. 55) cites the results of animal tests employing Pavlovian conditioning procedures. On the basis of functional tests, animals were characterized as to types of central nervous system as follows: "strong" types (characterized by the presence of strong processes of cortical excitation) and "weak" types. Comparisons were made of the effect of feeding isocaloric diets providing either 60 percent versus 15 percent of the total calories from fat or 20 percent versus 65 percent of the calories from carbohydrates; it was concluded that high fat diets weaken and that high carbohydrate diets strengthen the excitability of the cerebral cortex. The observed changes were more pronounced in animals of the "weak" nervous type. Studies of the effect of a high intake of dietary protein show an increase in excitability and also a suggestion of a differential effect according to nervous types.

Biological Rhythms. Finally, some consideration should be given to periodic variations in behavior and physiologic function based on the endogenous rhythms. These have strong implications for many problems in applied physiology, for example, with regard to

day-night shift workers, to the difficulties of resynchronizing with a different environment after long-distance space flights, and to social interactions. The theoretical aspects of daily periodicities have been well documented (ref. 56) and will not be considered here.

The habitability study conducted at Ames Research Center during the Spring of 1962 provided the opportunity to evaluate metabolism with regard to endogenous rhythms and in its relationship to human behavior. Briefly, two men were isolated and enclosed in a volume of approximately 130 ft³ during a 7-day simulated return trip to the moon. The daily ration (components of the IF-10 Rations) was constant during the "flight," for four days prior to and three days after the test, and provided daily 2,000 kilocalories. During confinement, the subjects adhered rigorously to a 4-hour work-rest cycle; urine specimens were obtained for those periods, and analyzed for sodium, potassium, calcium, and nitrogen content. The data were then examined for evidence of periodicity and both subjects showed definite frequencies in the urinary excretion of those substances with periods of 1 and 2 cycles per day. For example, the spectral analysis of urinary nitrogen during the period of confinement is shown in figure 1. The periods were independent of the feeding schedule and generally unrelated to time of day.

Correlations have been drawn between urinary mineral and nitrogen excretion and the scores obtained from tests of information acquisition ability administered during the corresponding work periods; these are shown in table VI. Urinary sodium, potassium, and calcium content were related ($p < 0.05$) to the errors made during information acquisition; nitrogen excretion was not. While it is impossible to establish a direct cause-effect relationship here, our results suggest an interplay between physiologic function on the one hand, and certain aspects of human behavior on the other. However, further scientific studies are necessary in order to test this hypothesis and to pursue the relationship to its practical conclusions.

In summary, several metabolic problems which are pertinent to extended space exploration and which seem ready for solution have been presented. Not to seek answers to these problems is to assume that man can overcome certain limitations by sheer strength of will power. Such an assumption is fallacious, and solutions must be found if man is to live successfully to his fullest capabilities in a new and unusual environment.

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TABLE I.- PHYSIOLOGIC EFFECTS OF IMMOBILIZATION

		Reference
Venous pressure	-	(1)
Blood volume	-	(1),(2),(3),(4)
Pulse pressure (orthostatic test)	-	(4)
Pulse rate (orthostatic test)	+	(4)
Nitrogen excretion	+	(4)
Calcium excretion	+	(4)
Phosphorus excretion	+	(4)
Sulfur excretion	+	(4)
Potassium excretion	+	(4)
Creatine tolerance	-	(4)
Sugar tolerance	-	(5)
Muscle strength	-	(4)
Exercise tolerance	-	(4),(6)
Basal metabolism	-	(4),(7)

+ or - refers to relative change as compared with a fit subject.

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²Taylor et al.: Am. J. Physiol. 144:227, 1945

³Barr et al.: Conf. Rpts. Josiah Macy, Jr., Foundation, 1945.

⁴Deitrick et al.: Am. J. Med. 4:3, 1948.

⁵Blotner: Arch. Int. Med. 75:39, 1945.

⁶Taylor et al.: J. Appl. Physiol. 2:223, 1949.

⁷Keys: Conf. Rpts. Josiah Macy, Jr., Foundation, 1944.

TABLE II - EFFECT OF HELIUM ON THE RESPIRATORY GAS EXCHANGE
(ML/GM ANIMAL/HR) OF MICE - EXPERIMENTS CONDUCTED AT SEA
LEVEL

Mouse	Oxygen uptake		Percent change	Carbon dioxide production		Percent change
	20% O ₂ - 80% N ₂	20% O ₂ - 80% He		20% O ₂ - 80% N ₂	20% O ₂ - 80% He	
A strain ♂	2.75	3.86	40	2.60	3.60	38
C3H ♂	2.52	3.51	39	2.35	3.25	38
Swiss ♂	2.29	3.54	54	2.17	2.96	37
Swiss ♀	2.26	3.69	63	2.25	3.17	41

TABLE III.- PARTIAL PRESSURE IN MM HG OF COMPONENTS OF THE

EARTH'S ATMOSPHERE AND SPACE CABIN ATMOSPHERE

	Earth 1 atm	Space cabin 1/2 atm	Space cabin 1/3 atm
Oxygen	155	155	155
Carbon dioxide	0.2	< 10	< 10
Nitrogen	588	208	108
Water vapor	12	12	12
Argon	5.7	---	---
Other rare gases (H ₂ , Ne, He)	< 0.1	---	---

TABLE IV.- DAILY DIETARY ALLOWANCES¹ FOR MAN

	Calories	Protein (gm)	Calcium (gm)	Iron (mg)	Vitamin A (I.U.)	Thiam. (mg)	Ribo. (mg)	Niacin (mg equiv.)	Ascorbic acid (mg)
NRC, 1958	3200	70	0.8	10	5000	1.6	1.8	21	75
AR40-564	3600	100	0.7	--	5000	1.7	2.0	16	75

¹Intended for persons normally active in a temperate climate.

TABLE V.- VOLUME AND COMPOSITION OF INTESTINAL GASES FROM RATS
FED DIETS VARYING IN PROTEIN AND CARBOHYDRATE SOURCE

Diet	Volume, ml	H ₂ , (%)	O ₂ , (%)	N ₂ , (%)	CO ₂ , (%)	CH ₄ , (%)
Dry skim milk	8.7	42.3	1.4	13.2	41.2	1.9
Casein	3.9	26.0	1.4	11.7	52.1	8.7
Corn dextrin	5.1	25.9	0.5	12.9	58.5	2.2
Dextrose	0.9	21.0	2.7	31.5	44.2	0.6

From: Armed Forces Food and Container Rpt. 38-62.

TABLE VI.- RANK-ORDER COEFFICIENT OF CORRELATION
BETWEEN URINARY EXCRETION AND PERCENT ERRORS
IN INFORMATION ACQUISITION (N = 21)

	Subject R	Subject S
Error X sodium	0.781*	0.577*
Error X potassium	.762*	.567*
Error X calcium	.600*	.625*
Error X nitrogen	.152	.244

*p < 0.05

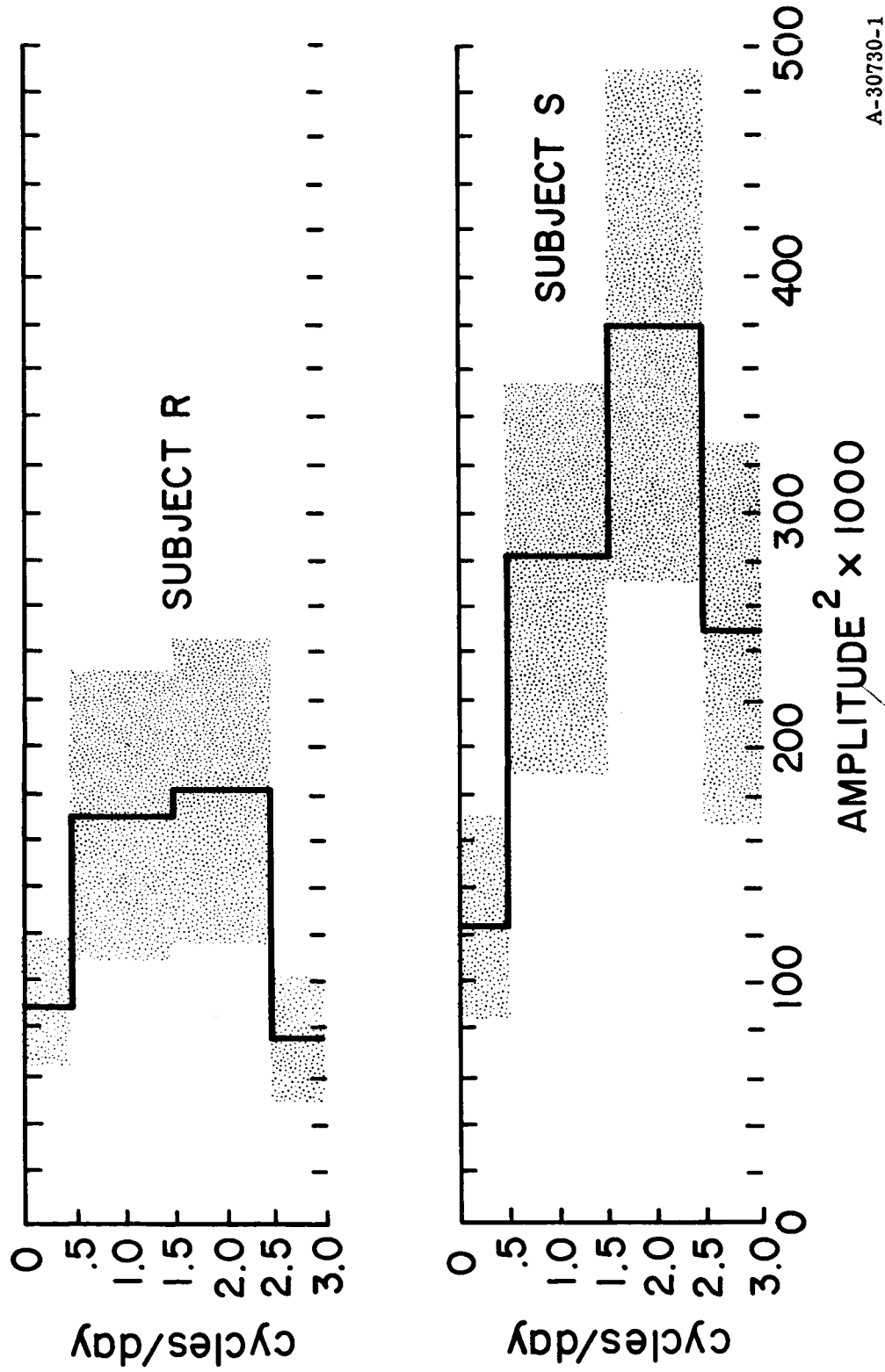


Figure 1.- Power spectral estimation of the frequency of urinary nitrogen excretion of two test subjects during 7 days of confinement. (The 80-percent confidence interval is depicted by the shaded areas. The amplitude shown on the abscissa is in arbitrary units.)